Managing Analysis Models in the Design Process

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Design of large, complex space systems depends on significant model-based support for exploration of the design space. Integrated models predict system performance in mission-relevant terms given design descriptions and multiple physics-based numerical models. Both the design activities and the modeling activities warrant explicit process definitions and active process management to protect the project from excessive risk. Software and systems engineering processes have been formalized and similar formal process activities are under development for design engineering and integrated modeling. JPL is establishing a modeling process to define development and application of such system-level models.

I. Introduction

SIM PlanetQuest[22,12] (formerly called Space Interferometry Mission), scheduled for launch in 2015, will determine the positions and distances of stars several hundred times more accurately than any previous program. This accuracy will allow SIM to determine the distances to stars throughout the galaxy and to probe nearby stars for Earth-sized planets. SIM is expected to open a window to a new world of discoveries. The SIM spacecraft is an optical interferometer and combines light from two telescopes as if they were pieces of a single, gigantic telescope mirror. The SIM spacecraft concept is shown in Fig. 1.

Because of the obscuring effects of the Earth's atmosphere, the detection and characterization of small planets with normal orbits like Earth is extremely challenging using ground-based telescopes. New space telescopes like the Spitzer and James Webb Space Telescopes, the Kepler mission, and the Space Interferometry Mission, will search for newly formed planets circling young stars, take planetary surveys of thousands of far away stars, and detect planets only a few times larger than Earth around very nearby stars. The results from these telescopes will be used in the design of an advanced space telescope, the Terrestrial Planet Finder[12], to be launched during the next decade. The Terrestrial Planet Finder will be capable of finding Earth-like planets and detecting the chemicals in their atmospheres.

The Decadal Survey for Astronomy and Astrophysics of the 1990s set forth a lofty goal: develop a revolutionary space telescope that would "... achieve a 1,000-fold improvement in our ability to measure celestial positions." This new instrument would enable scientists to rigorously test accepted astrophysics theories, resolve fundamental questions about our galaxy, and detect Earth-size planets around other stars, among many other science objectives.

Figure 1. SIM Spacecraft Concept

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II. Integrated Modeling

Many large projects employ complex, multi-disciplinary analysis models to assess design performance, to guide the design teams through trade studies and to explore the design space. SIM has developed several integrated system performance models that incorporate mechanical, thermal and optical physics simulations since this combination is critical to the instrument.

The last technology milestone entails building a composite picture of SIM instrument performance from all the technology activities (both testbeds[15,17,8,11,9,22,1] and analysis[17,16,21])[18]. This will represent the final statement of what level of scientific precision the technology that has been built over the past decade will be able to provide when it is built into SIM.[16] Additional factors have been introduced to the testbed, such as thermal control, vibration and material properties that simulate the realistic conditions of the spacecraft. See Fig. 2, Test Setup. This milestone must demonstrate that these factors will not degrade performance to the point that the results fall below the requirements. The project completed this milestone in 2006 and model validation results have been reported previously.[19,10]

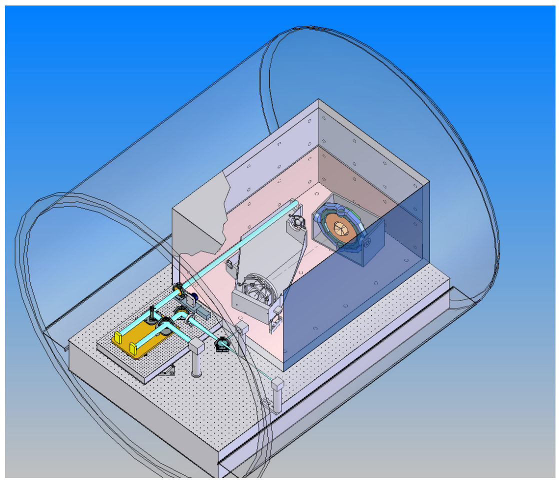

Figure 2. Test Setup

The JPL integrated modeling of this milestone test has been reported[19, 10] and Ref 6 describes the complexity and precision required for SIM.

III. Design Process

JPL, like many aerospace organizations, has formalized its design processes through activities such as re-engineering and is currently working toward further improvement and certification based on CMMI.[3, 20, 2] While CMM, and later CMMI, was originally the domain of software development, a wide variety of disciplines, such as Systems Engineering, have been incorporated in recent extensions. Process models for hardware development, and design engineering in particular,[3] are being developed.

Incorporating Computer Aided Engineering (CAE) analysis activities into the Product Data Management (PDM) system has been one aspect of process improvement. This author, and others, have reported developmental example activities that illustrate both the practices and benefits, although broad adoption has not begun.[5, 7, 4, 14]

Many of these models are used as part of design trade studies. CMMI calls out basic analysis and data management activities.[24]

The activity reported in this paper reflects the initial efforts at JPL on the SIM project to codify these guidelines into a specific Model Management Process.

IV. Model Management Process

A. Background

All recent projects at JPL have had system models to guide the design evolution through trade studies. In this respect, SIM practices are no different. Since inception, however, SIM project management has anticipated that the system will be inherently untestable during final integration and that many aspects of the system performance and operational parameter settings will have to be based largely on models.

As a result, SIM established and recently completed a technology demonstration program of 8 milestones to provide the verification basis for the system models.

B. Issues with Current Process

The SIM integrated models are very large and their development grew up out of the current Work Breakdown Structure in an ad hoc fashion during the first half of the Preliminary Design Phase. A champion, typically a senior member of the Instrument Systems Engineering team, guides the model development and application toward generation of performance requirements. Subsystem design teams supply the mechanical and thermal models and a small team of users apply the model to development of the system requirements. As the Instrument Systems Engineering team has grown in size, this causes a significant competition for resources.

The system models are large, multi-disciplinary physics-based model systems. For example, the structural dynamics model has more than 500k degrees of freedom and the thermal model has ~200k radiation elements. Substantial new processes for model assembly and solution had to be developed and solution times can stretch to 5 days.

As the model complexity grew through the first 3 cycles, the time from kickoff to results has stretched to 12 months. In that time, the subsystem design teams had pushed the hardware designs well past the point that the integrated modeling results retained any relevancy.

Finally, the standing project review boards have consistently been asking “How do you know the models are right?” Initially, careful management of the development activities and the successful technology demonstration experiments provided the required response, but the project knew that Detail Design, system Assembly and Test, and initial Operational Checkout would require a substantially more structured approach.

C. Prototypical Process

There are several system models which are based upon combinations of mechanical, thermal and optical models. Fig. 3 shows the proposed model development and application process. Elements of this newly formalized process have been incorporated into recent model development cycles.

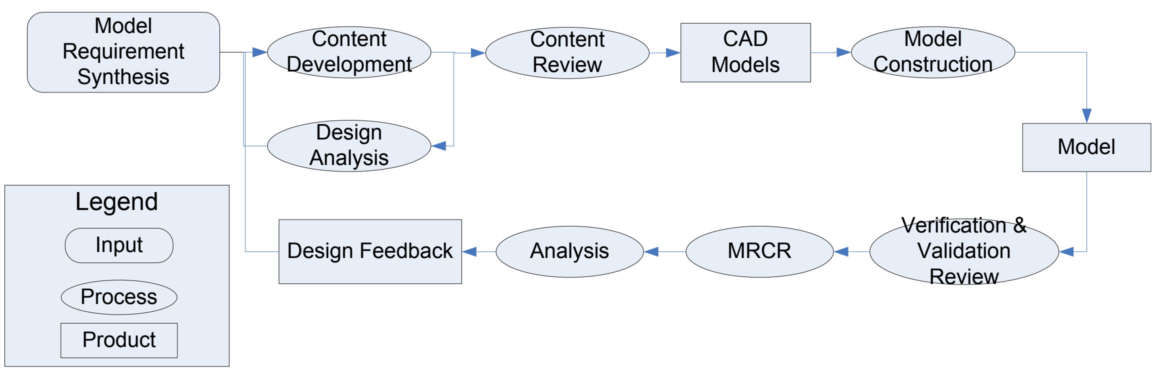

Figure 3. Prototype Modeling Process

The central elements are the well formed, traditional modeling activities of mechanical and thermal analysis. An initial Content Development activity has been explicitly called out. This includes semi-formal contracts with the subsystem design teams that list the design trade results to be incorporated. Prior to beginning development of the analysis models, the design basis is reviewed against the agreements and plans prepared to handle missing or incomplete design elements.

Another new process step which will be a significant activity during Detail Design is the Verification Review. In modeling cycles to date, the analysts provided model documentation and a delivery presentation which provided the only formal review. The process now establishes planned time and resources to strengthen this critical step.

JPL hardware development culminates in the Hardware Requirements Certification Review (HRCR) as the final gate before delivery of that assembly to the next higher assembly during final integration. The Model Requirements Certification Review (MRCR) is analogous. In a brief perfunctory meeting, the checklist of readiness criteria is reviewed.

Each model development activity will tailor this process to include the requisite physics-based models, required model functional capability and verification and validation activities.

D. Requirements

The initial requirements activity formalizes steps that set the scope for the ensuing model development phase. The end user's functional needs and model performance requirements are elicited, defined and agreed upon. This includes level of detail, physical processes to be modeled and model functional capabilities.

This activity also includes definition of the verification and validation process that follows model development.

Both the model development manager and the sponsoring end user are identified and participate actively in this activity.

E. Verification

The modeling process explicitly calls for verification and validation of the system models to reflect the significant role these play in producing the SIM Instrument. Fig. 4 illustrates the steps to verification.

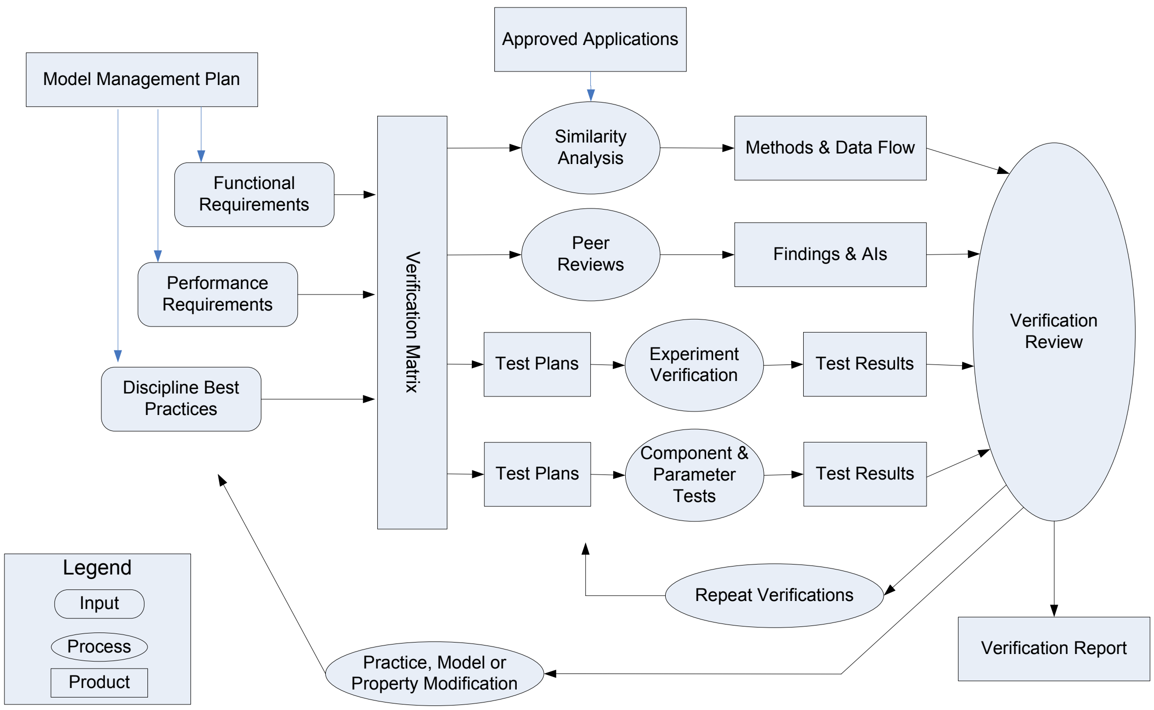

Figure 4. Model Verification Process

Model verification process lists candidate approaches to verification of all the aspects of the model basis. These include the required physics, numerical methods, tools and material properties. The model developer prepares the verification plan before development begins and demonstrates satisfaction of the verification plan prior to delivery of the model to the end user.

V. Conclusion

The model management process outlined in this extended abstract has been through initial review and is expected to be implemented. The final paper will summarize its initial application to ongoing modeling activities.

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